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HEARING CONSERVATION AND ACOUSTIC HABITABILITY FOR SUBMARINERS

by

J. Donald Harris

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4305.08-3008DEE5.01

Released by:

J. E. Stark, CAPT MC USN
COMMANDING OFFICER
Naval Submarine Medical Center

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SUMMARY PAGE

THE PROBLEM

To survey the history and current status of the major acoustic conditions in the U.S. Naval Submarine Force which affect hearing and acoustic habitability.

FINDINGS

Six specific problem areas were identified that are concerned with broad-band noises such as diesels, rockets, gunfire, and pure-tone sonar pulses in the water affecting swimmers and divers, in sonar headphones, and in the forward compartments near an active transducer. Priority and direction for future research problems are indicated. A criterion of 85 dB sound pressure level is recommended for airborne sonar pulses in living compartments, both for hearing conservation and for habitability, with future research in this area having relatively low priority. A higher priority should go to research on several aspects of underwater hearing.

APPLICATION

For guidance to researchers and administrators in assigning priorities to research projects in submarine medicine.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4305.08-2008DEE5 - Development of Damage Risk Criteria and Habitability Standards For Exposure to Sonar Transmissions. The present report was approved for publication on 13 October 1971. It is Report No. 1 on the indicated Work Unit and has been designated as Naval Submarine Medical Research Laboratory Report No. 682.

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ABSTRACT

This report concerns several acoustic conditions in submarines which are considered to be potentially hazardous to hearing and/or ship's habitability. Recommendations are made and priorities suggested for further research:

(1) Broad-band noise is currently covered by the BUMED Hearing Conservation Program.

(2) The effects on the ear of impulsive noise (rockets, gunfire) are not well known, but these are not primarily submarine problems.

(3) The fundamental characteristics of underwater hearing are largely unknown, and submarine medicine should sharply increase its basic and applied research in this field.

(4) Intense sounds in the sonar headphone occasionally exist, but some applied research currently in progress at the Naval Submarine Medical Research Laboratory (NAVSUB MEDRSCHLAB) should solve this relatively simple problem.

(5) Own-ship echo-ranging creates hazardous levels, but at duty stations men can wear ear protective devices. In living areas where these cannot be used around the clock, a Damage Risk Criterion of 85 dB has proved acceptable for 24 days with sonar as now used. If future operations should materially increase the acoustic load on the ear, some short-term laboratory studies and monitoring at sea should be the techniques of choice.

(6) Acoustic habitability with own-ship echo-ranging has proved in repeated studies to be no problem, unless sound levels are intense enough to affect the ear adversely. Thus the ear, as the body's most sensitive system to sound, is also the most fragile, and can serve as the best index of habitability. There is no Navy need for further confinement studies on the effect of sonar pulses on non-auditory systems of the body.

TABLE OF CONTENTS

HEARING CONSERVATION AND ACOUSTIC HABITABILITY FOR SUBMARINERS

INTRODUCTION

Interest and Assumed Responsibilities of NAVSUBMEDRSCHLAB In-Subject Areas.

Hearing conservation and acoustic habitability fall within the mission of the Bureau of Medicine and Surgery [1] to safeguard and promote the health of naval personnel, by providing professional and technical guidance and assistance to the Navy in the following ways: (1) in the planning and conduct of research, development, test, and evaluation of weapons systems which create potentially hazardous noise, (2) in evaluating the health aspects of the total shipboard environment in coordination and cooperation with those responsible for design, specifications, and standards of spaces and equipment, (3) in establishing environmental standards for the prevention of personnel injury including hearing, and (4) in initiating and conducting research, development, test and evaluation efforts in medical, biological and behavioral sciences.

Thus, the responsibility of BUMED extends far beyond the medical care of personnel exposed to high noise; by advice and assistance to the Chief of Naval Material and to System and Fleet Commands and by itself performing research, BUMED's responsibility and prerogative extend to all human factors aspects of noise pollution beginning with the initial design and evaluation of weapons and spaces involved.

These responsibilities, as applied to the Submarine Force are assumed to devolve upon NAVSUBMEDRSCHLAB as the field laboratory of BUMED for submarine problems.

Scope of the Problem.

There are several acoustic conditions of concern existing in submarines: (a) broad-band continuous noise, as in diesel enginerooms, can damage hearing; (b) impulsive sounds, as rocket or gunfire, (c) sonar echo-ranging in proximity to swimmers and divers results in potential hearing damage; (d) surface ship echo-ranging in proximity to submarines, and occasional sounds created by own-ship, result in potentially damaging levels in sonar headsets, (e) echo-ranging creates potentially damaging levels in own-ship spaces; and (f) noise levels in crew living spaces due to own-ship echo-ranging may be lower than potentially damaging to the ear yet may be deleterious to general health and/or performance and thus be unacceptable.

Purpose of This Report.

This report discusses in order the present status of these six acoustic conditions of concern, to support current recommendations and to serve as a guide for further research and recommendations where needed.

A: BROAD-BAND CONTINUOUS NOISE

1. The Damage Risk Criterion. The BUMED Hearing Conservation Program[2] takes account of this type of noise, still common in the diesel enginerooms of the submarine fleet, by imposing a criterion of 90 dBA (i.e., dB on the "A" scale of a sound level meter) at which level personnel protective devices and procedures shall be instituted, including a more detailed study of the spectrum of the noise. Botsford[3] found that the 90 dBA criterion coincided for 80% and 75 industrial noises with the more detailed criteria written by a Working Group of the NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics[4] of which the writer was a member. In 4% of these noises, personnel would be underprotected by the 90 dBA criterion, in 16% they would be overprotected. The personal cost to the men in the 4% of the noises being underprotected, and the cost to the Navy of overprotecting men in the 16% of noises, is at least on the conservative side; but note that the BUMED program calls for a detailed analysis of noises of 90 + dBA, so that by the application of the criteria in [4], even the men in the 4% of noises are protected.

A complication arises in that the criterion in that report was designed to protect only 50% of cases, whereas a more humanitarian goal would be to protect 85%, the 15% remainder being handled by audiometric monitoring protective devices, and even by the Veterans Administration. The standard deviation of noise-induced hearing loss is such that 85% of the men would be protected if the criterion were reduced by 5 dB, i.e., from 90 to 85 dBA. It would seem at first glance then that the BUMED criterion of 90 dBA is too high. However, it was found in a 7-year-long study at NAVSUBMEDRSCH-LAB of submarine diesel operations[5] that normal healthy young men can withstand somewhat louder noises (5-10 dB) than industrial workers on whom most criteria are based. This corroborates a similar conclusion by Quist-Hanssen[6] with Norwegian naval personnel. Thus the BUMED criterion of 90 dBA for continuous noise (with its additional requirement for spectral analysis) appears conservative and in no need of further research of special priority.

2. Engineroom Noise. On the basis of the assumption in [4] that a hearing level is significantly deteriorated if it exceeds 10 dB at 1 kiloHertz, 15 dB at 2 kiloHertz, and 20 dB at or above 3 kiloHertz, this Laboratory for the past decade and more has performed monitoring audiometry on the engineroom crews of 72 submarines, 28 of them nuclear-powered, involving over 1000 individuals, for each of whom a record is kept of his yearly or more-frequent audiograms entered consecutively. Each man developing a loss especially at 3-6 kiloHertz is given counselling; and a report is sent to his Squadron Medical Officer with recommendations, if any. No difficulties have been experienced in implementing this course of action.

Conclusions on Engineroom Noise.

It is felt (1) that the criteria of significant hearing loss established in[4]

correctly assess an incipient medical/communication problem, (2) that the BUMED noise Damage Risk Criterion of 90 dBA is correctly conservative, and (3) that the provisions of [2] for audiometry, education, and personnel disposition should be maintained indefinitely with no need for high-priority research.

3. Missile Noise. NAVSUBMEDRSCH-LAB has evaluated the short-duration (about 1-sec) broad-band noises during firings of REGULUS-I missiles from cruisers[7] and found that levels/durations did in fact exceed Damage Risk Criteria set by BUMED, but that the standard Navy ear plugs or muffs were more than adequate to protect the individual occasionally subjected to these brief bursts.

On the other hand, on the submarine USS GROWLER (SSG-577) with the more powerful REGULUS-II, the acoustic problem was not primarily the launching, but the extreme and sustained (up to 45 min) noise during engine run-ups. Levels as much as 21 dB above the criterion for 2 run-ups per day exist in the damaging frequency range but again these levels can be reduced in the ear canal to safe effective levels by use of the standard protective devices issued by the Navy[8].

Conclusions on Missile Noise.

Missile noise at this time in the submarine fleet constitutes an auditory hazard which standard protective devices can adequately control; no basic research program directed solely to this problem is currently advisable.

B: IMPULSIVE SOUNDS (GUNFIRE)

Though relatively rare, there are occasions when submarine personnel are subjected to noise from small arms, or small cannon fire. Ref. 2 follows a general recommendation that for every such exposure in a test or training situation, even a single pistol shot, the ear of the firer should be protected with a plug or muff, and, similarly, for those exposed to artillery fire under any situation.

Some research should be done as to which feature(s) of the acoustic wave from gunfire is (are) the most significant for hearing damage, whether peak sound pressure level, rise time to peak, duration of peak, etc.. Kryter offered a formula[9] (Table 27) for a composite Damage Risk and validated it by comparing (with good success) the threshold shifts found in 7 different experiments with the shifts as predicted from his formula. (Kryter first converts the time-pressure waveform of the impulse, as seen on an oscilliscope, to energy spectrum level in third-octave bands, notes the level of each impulse, and allows for recovery during rest periods, between pulses.) Kryter's formula[9] (Table 27) incorporating the stimulus features of peak over-pressure,

spectrum, exposure duration, number of impulses, and recovery period between exposures, would seem not to overlook anything, and when further validated by field studies, to lead to Damage Risk Criteria which BUMED could incorporate into its Hearing Conservation Program.

The protective devices appropriate to control gun blast are not those appropriate for loud continuous sounds. The problem is to absorb the energy of the first pressure wave which can damage the eardrum, ossicles, etc., as well as the tissues of the inner ear. At least three earplugs are commercially available which absorb the pressure wave, the "Selectone", the "Lee Sonic Ear-Valv", and the "Gundefender", all of which incorporate a little hole through the device so that frequencies around 1 kiloHertz and lower are only slightly attenuated and thus ordinary speech communication can be carried on, (for an excellent discussion for the general reader, with sketches and proprietary information see[10]).

Conclusions on Impulse Noise.

Impulsive noise such as gunfire is a serious problem for the Navy, and research looking toward validation and refinements of Kryter's assumptions should be actively pursued on a high priority. Of all units in the Navy, the Submarine Force is perhaps affected the least. Research should be undertaken by a medical research facility concerned with surface vessels, a field medical laboratory, such as that in the Marine Corps, or by transferring funds to the Naval Submarine Medical Research Laboratory which is ideally suited for such research, and increasing the priority of such work at NavSubMedRschLab. For the submarine fleet at the moment it is sufficient that ear protection be worn by personnel during test and training whenever a single impulse is to be expected, and at all times during exposure to artillery fire.[2]

C: ACTIVE SONAR EFFECTS ON SWIMMERS AND DIVERS *

The introduction of powerful active sonar systems which transmit at frequencies within the range of human hearing has created concern that such transmission during in-port systems tests may be damaging to the hearing of divers. This concern was reflected in a number of port command rulings governing the operation of active sonars while divers were operating in the area. Existing hearing conservation standards were not applicable to such situations since the human ear does not operate the same way in water as it does in air.

In order to establish damage risk contours for exposure to intense underwater sound it would be necessary to parallel, in part, the experimental work which led to the formulation of airborne noise standards. As a minimum, it would be necessary to determine whether

** This section was prepared by Mr. Paul F. Smith, Auditory Research Branch, Naval Submarine Medical Research Laboratory.*

a simple transformation of airborne standards would cover conceivable underwater situations and the nature of the transformation (e.g., adding x dB). At worst, the relatively limited variety of probable underwater noise conditions would have to be individually investigated.

To date, it has not been possible to study this question systematically. Rather, this Laboratory has attempted to provide competent guidance by investigating specific problems posed by line commands and especially by NavUnderwaterSysCen. NAVSUBMEDRSCHLAB reports[11 thru 15] obtained data on the effects on the hearing of divers of exposure to AN/SQS-23 and AN/SQS-26 sonar transmissions. These reports and subsequent experimentation funded by COMNAVSHIPSYSCOM led to the establishment of the safe diving distances reported in[16].

Reference 16 provides a family of curves showing safe diving times and distances from currently operational sonar systems. Curves are provided for both hooded and bareheaded divers. For most situations, a diving master need only assume that the system is operating at its maximum output level and duty cycle, determine his distance from the transmitter, and look up the safe working time for his divers. In only a few cases will it be necessary to contact the Sonar Officer to determine actual transmit duty cycle and to determine sound pressure level at the diving site.

The general problem of how the ear functions underwater was studied by Smith[17 & 18] who showed that, at least for frequencies above 1 and 2 kHz, persons with air conduction hearing deficiencies but normal levels for bone conduction hearing are as sensitive to underwater sound as are divers with normal air conduction levels. This finding supports the notion that underwater hearing is mediated by a bone conduction mechanism. The problem of protecting divers from intense underwater sound cannot be solved by the use of earplugs or ear muffs as is the case of airborne exposure. It is necessary to protect the whole head, and in some cases perhaps the whole body, from intense underwater sound.

Montague and Strickland[19] found that neoprene hoods reduce hearing sensitivity by 20 to 30 dB in the frequency region 1 to 6 kHz. Smith[17] confirmed this finding and showed that the attenuation provided by divers' hoods is as great at 99 feet as near the surface. Montague and Strickland also found that divers wearing hoods would tolerate about 10 dB higher levels at 1.5 kHz than they would bareheaded. Smith subsequently found hooded divers would tolerate levels as high as 192 dB re .0002 dynes per sq. cm^2 without complaint and for prolonged durations.

Concerning the upper limits of underwater hearing, Montague and Strickland found that only one of their 23 subjects would tolerate brief exposure to 1.5 kHz tones at levels up to 179 dB re .0002 dyne per cm^2. One-half of their sample would not tolerate levels in excess of 172-175 dB. These levels are 40 to 60 dB above commonly cited "thresholds of pain" for airborne exposure. Smith et al[20] found that all six of their subjects would tolerate a 1-sec

tone pulse at 50% duty cycle, 3.5 kHz at 178 dB for a full 15 min. In that study, it was found that the differences in level in air and under water required to produce comparable hearing threshold shift was about 60 to 70 dB. Smith felt that his subjects would have tolerated even higher levels. This discrepancy between Montague and Strickland's and Smith et al 's results may be due to differences in hearing sensitivity at the frequencies used. Smith's threshold data[17] indicated that at 1.5 kHz the ear under water is 10 to 15 dB more sensitive than 3.5 kHz. It may also be that, with additional coaching, and exposure, Montague and Strickland's subjects would have tolerated higher levels.

Conclusions on Underwater Hearing Damage.

The approach of NAVSUBMEDRSCHLAB has been to meet each problem as it comes. Sufficient data to draw comprehensive Damage Risk Contours for exposure to underwater sound are still lacking. Although present hearing conservation needs seem to be met by[16], future sonars may have lower transmitting frequencies than current systems. For such systems we cannot at present propose standards. More basic research on underwater hearing should be pursued with high priority, and a BUMED laboratory should keep in the closest touch with the operating forces in order to monitor and advise on potentially hazardous conditions as they develop.

D: SURFACE SHIP ECHO-RANGING AND THE SUBMARINE SONARMAN

1. Background. There exists heavy to very heavy acoustic inpingement on the target hydrophone when surface ships in an exercise seek to converge on a target submarine, under certain obvious conditions of numbers of ships, ranges, depth, etc. This is, of course, amplified and led to the sonar headset, and levels created which far exceed Damage Risk Criteria.

This problem, foreseen by the sonar systems designers, was controlled by building a voltage limiter into the equipment so that potentially hazardous levels would never exist at the headset. When, therefore, sonar technicians began to appear at NAVSUBMEDRSCHLAB in the fall of 1970 for routine annual audiograms with accounts of very loud and even painful levels in their headsets, two steps were taken: (1) an inquiry through Mr. B.B. Burnham, Chairman of the NUSC Ad Hoc Committee on Auditory Damage, on which NAVSUBMEDRSCHLAB has representation, as to whether the limiters on the equipment did actually operate and if not, why not; and (2) an examination during the winter of 1970-1971 of the hearing of 53 sonar watch-standers aboard eight submarines, USS POLLACK (SSN-603), USS GREENLING (SSN-614), USS DACE (SSN-607), USS GATO (SSN-615), USS NAUTILUS (SSN-571), USS BILLFISH (SSN-676), USS TIGRONE (AGSS-419), and USS BERGALL (SSN-677) involved in exercises in which

this acoustic problem has been prevalent.

a. Disabling the Voltage Limiter. It developed when NUSC looked into the matter on several submarines, that, for what sounded to them as good reasons, sonar technicians had often entered the electronic circuits and either by-passed the limiter altogether or set its cut-off voltage much higher. Thus the problem becomes complicated, since although it may be possible to attempt a tamper-proof limiter, for example by burying it in the headset itself, still an ingenious crewman might well circumvent the designer, perhaps by substituting his own earphone.

b. NAVSUBMEDRSCHLAB Audiometric Surveys, pre-summer 1970-winter 1970-1971.

Thirteen of 53 sonar-watchstanders exposed to the noises during the summer of 1970 on whom we had pre- and post-exposure data in our files, revealed mild losses (15-55 dB) confined to 3-8 kiloHertz in one or both ears. Of these, 6 had a loss of no more than 15 dB at only 1 frequency in one ear - i.e., quite negligible as such, but a portent of further loss with continued years of exposure.

2. Experimental Results.

a. Audiograms on Cruise of USS GATO (SSN-615) of 19-31 JAN 1971.

With equipment and instructions provided by NAVSUBMEDRSCHLAB, audiograms were collected on 22 ears on 11 men before and after watches in surface ships echo-ranging. About half the ears had losses of over 20 dB at 4 and/or 6 kiloHertz (briefly reported in[21]).

b. Audiograms on Cruise of USS GATO (SSN-615) of 21-31 MAR 1971.

Naval Underwater Systems Center, Code EB2, having modified two of the three sonar headsets on USS GATO, conducted a comparative study underway between 6 sonar technicians using the unmodified set and 6 the modified set[21]. As before, on 19-31 JAN 1971, about half of the men using the unmodified set suffered a temporary hearing threshold shift which exceeded a widely-disseminated critical loss (15 dB shift remaining after 30 min recovery, see[22]) while only one of the men using the modified set did so.

3. Administrative Action.

On the basis of a series, begun in 1959, of three NAVSUBMEDRSCHLAB reports[23,24&25] a Damage Risk Criterion in the headset was recommended by NAVSUBMEDRSCHLAB at 90 dB considering the worst cases of pulse duration, level, pulse repetition rate, and watch duration; but for less frequent exposures, as in many at-sea operations, the criterion might be raised to 95 dB (see[26]). The urgency of the problem was such that COMSUBLANT directed NavUnderwaterSysCen and NAVSUBMEDRSCHLAB jointly to look further into the matter and make recommendations[27]. In partial reply[28], NAVSUBMEDRSCHLAB recommended that fail-safe limiters be set to clip at 95 dB but if the clipper must be set at 100 dB, an individual

should not stand more than a 2-hour watch.

4. Discussion.

The truly crucial questions are, Why should the sonar technician re-set the limiter in the first place? What information is he losing when the current type of limiter is operating, at say, 90 dB, 95 dB, 100 dB? At what levels should the limiter be set to protect the ear during heavy vs. very heavy echo-ranging? Can some other type of limiter be suggested to preserve hearing and still preserve the information the sonarman can get from the sea - one thinks of a limiter with a duration for each ping of 1-3 sec after which the information from the sea is not limited till the next ping, or a type of automatic volume compression with instantaneous attack and release time (for a totally new concept here as worked out in a Danish hearing aid where the acoustic problem is almost identical, see[29]). Research on these and other notions should be pursued aggressively, between a laboratory able to create and adapt appropriate circuits and components, and a psycho-acoustic laboratory experienced in sonar and able to state what safe limits can be withstood by the ear and to state what sonar information is lost, if any, when certain equipment solutions are proposed. At the moment, an approach along all these lines is being initiated jointly between NavUnderwaterSysCen and NAVSUBMEDRSCHLAB by way of a task from NAVSHIPS[30]. This effort warrants high priority.

5. Conclusions on Auditory Hazard in Sonar Earphones.

A potential auditory hazard exists for the sonar watchstander exposed to enemy echo-ranging. A limiting (clipping) circuit set at 90 dB has been shown to eliminate the hazard, but it may be intentionally disabled by the sonar technician in an effort to extract more information from the sea. Research should be given high priority to set a low-risk clipping level and to ascertain the loss, if any, in sonar detection and recognition at various clipping levels. Meanwhile, research should seek to canvass other principles of suppressing the incoming sonar pulse without degrading sonar information. Two examples are offered. NavUnderwaterSysCen and NAVSUBMEDRSCHLAB are currently engaged jointly in these activities.

E: AUDITORY DAMAGE DUE TO OWN-SHIP ACTIVE SONAR

1. Introduction.

In 1958, sonar systems design engineers at NavUnderwaterSoundLab alerted NAVSUBMEDRSCHLAB personnel to the fact that hunter/killer submarines in the near future would commonly be utilizing very powerful active-mode sonar and that hazaradous noise levels would certainly be recorded in sonar equipment spaces near the transducer and in fact throughout the fore part of the ship.

2. Previous Research.

a. NAVSUBMEDRSCHLAB Study in 1959.

With knowledge of the frequency, the range of pulse durations, and probable pulse repetition rates, NAVSUBMEDRSCHLAB combined in a variety of ways and gave them to a total of 156 Navy enlisted personnel for session durations of 5-25 minutes[23]. In this first experiment, no attempt was made to simulate sonar conditions, but only to look at the effect of each parameter while partialling out the simultaneous effects of all others. It was found that auditory fatigue in dB grows linearly with sound pressure level and with log of session duration, as had been generally found for continuous broad-band noise. For a pulse duration of 70 millisec or less, and duty cycle of 17.3%, a potentially permanent effect on hearing occurs at an asymptote of about 100 dB within a couple of hours, while if the pulse duration is lengthened and/or duty cycle increased, the effect would appear at about 90 dB.

However, there were then no published formulations or Damage Risk Criteria for short stimulus bursts against which to test these data, and much work remained to be done. Unfortunately, it developed that the extensive work on noise was inapplicable, since a difference in auditory damage appeared between tones vs octave-bands of noise, ranging from an estimate of tones 12 dB weaker than noise being equally damaging[31] to 3.5 dB[23, p. 8] A conversion of 5 dB is often mentioned, but on the slightest of evidence, and the problem is still open.

b. Bolt, Beranek, and Newman, Inc. Survey in 1959.

A brief survey of the acoustic damage/habitability problem on the PERMIT class of submarine was made for NavUnderwaterSoundLab by Bolt, Beranek, and Newman, Inc.[32]. For an 8-hr. exposure at 4% duty cycle, a Damage Risk Criteria of 105 dB was suggested, but it was noted that this level was subjectively intolerable for even 30 min for most crewmen, and a habitability criterion of 80 dB was suggested, with 75 dB in sleeping areas.

c. SUBMEDRSCHLAB In-House Study in 1961.

A practical question was answered in 1961 by NAVSUBMEDRSCHLAB by a habitability/hearing conservation study in its Sound Suite, showing that the ear can withstand 30 hrs of pulses of 3.5 kHz at 90 dB, when the pulses are 1/4-sec long every 5 sec (duty cycle = 5%), but can withstand only an hour or two at 100 dB.

d. Bolt, Beranek, and Newman, Inc. Study of 1961.

Bolt, Beranek, and Newman, Inc. reported to NavUnderwaterSoundLab[33] a laboratory study using 1-sec pulses at 4.5 kHz every 25 sec (duty cycle = 4%), and suggested that if submarine active sonar operations were to be full-power of the order of 3-5 days per month, a level of 75 dB should not be exceeded in sleeping/eating/relaxation areas - i.e., where protective devices would not be convenient or acceptable.

e. SUBMEDRSCHLAB Audiometric Monitoring Begun in 1963 on this Problem.

Problem. In April 1963, NAVSUBMEDRSCHLAB began routine monitoring of the crew of USS TIGRONE (AGSS-419) and of NavUnderwaterSoundLab personnel on board TIGRONE exposed to the loud levels of BRASS sonar.

f. British Study of 1964.

In 1964, a British report appeared[34] which had utilized longish pulses every 30 sec (10% duty cycle) 24 hrs/day for 12 days. At 75 dB there was no cumulative threshold shift, but at 85 dB there was an increment of 6 dB temporary hearing threshold shift per log exposure duration which would be unacceptable if continued over many days. A level of 95 dB was quite unacceptable: after 5 days, about half the men had severe threshold shift and required ear protection, and after the cruise, 12 of the 66 men requested transfer. Seven days or more were required for full audiometric recovery, which in 2 men did not occur and was presumed to be a permanent loss.

g. Bolt, Beranek and Newman, Inc. Survey of 1964.

A Bolt, Beranek, and Newman, Inc. team analyzed the hearing conservation problem on USS TIGRONE (AGSS-419) using the Damage Risk Criterion[4], extrapolating where necessary, and suggested that a criterion of 100 dB could protect 85% of the men against 1-sec pulses at 1-2% duty cycle[35].

h. Joint NavUnderwaterSoundLab/Bolt, Beranek, and Newman, Inc. Study of 1965 on USS TIGRONE (AGSS-419).

In 1965, a joint field study appeared[36,37] which stated that what was then known for other sounds pointed to a Damage Risk Criterion of 100-110 dB for these pulsed tones, quite apparently too high. They exposed 12 men for 9 hours to pulses measured on the USS TIGRONE, at 93-108 dB, a pulse every 60 sec. This paper shows that 1 man exposed to 108 dB reached criterion hearing loss after 70 min, 1 man exposed to 102 after 120 min, and 1 man exposed to 93 dB after 4 hrs. It was suggested that for these pulse conditions a criterion of 90 dB should be set for indefinite exposures of no more than 8 hr/day.

i. NAVSUBMEDRSCHLAB Study of 1968.

In 1968, a further attack on the fundamental parameters was completed by NAVSUBMEDRSCHLAB[25] on 302 Navy enlisted personnel exposed for up to 2 hrs to 37-250 millisec pulses at 2.2 kHz, duty cycle from 0.1% to 100%, and levels from 105-120 dB. Especially important were the facts that pulses of 37 millisec had about as much effect as of 250 millisec, for the same duty cycle, and that the higher duty cycles had a disproportionately greater effect.

In 1968, the notion was prevalent that there might well arise new missions and threats which would necessitate prolonged active sonar and make the hearing conservation problem more acute. Table 1 shows all the hard facts to that

TABLE 1: STIMULUS CONDITIONS WHICH LED TO SUGGESTED DAMAGE RISK CRITERIA FOR SHORT PULSED TONES

Reference	Duty Cycle in %	Criteria Hearing Loss	Damage Risk Criteria Suggested
23	17.3	cum. loss at 4 kHz over 10 min.	Less than 100 dB for indefinite time.
	43	cum. loss at 4 kHz over 10 min.	Less than 90 dB for indefinite time.
24	5	TTS_2 at 4 kHz	90 dB for 30 hours.
32	4	TTS_2 at 4 kHz	75 dB for 3-5 days/mo. for habitability.
34	10	TTS_2 at 4 kHz	Less than 85 dB.
36, 37	1.6	TTS_2 at 4 kHz	90 dB indefinitely at 8 hr/day.
25		TTS_2 of 20-25 dB at 4 kHz.	Sheaf of curves: e.g., pulse duration of 250, duty cycle of 10%, 30-day continuous exposures; DRC = 92 dB.
	16.7	TTS_{15-50} of 20 dB at 6 kHz.	90 dB indefinitely at 8 hr/day.

date from which conclusions could be drawn. It is seen that the differences among the British studies and the studies supported/conducted at NavUnderwaterSoundLab and NAVSUBMEDRSCHLAB are extreme in that frequencies range from 2.2 - 4.5 kHz, pulse durations from 37-3150 millisec, duty cycles from 2 - 43%, and exposure durations from a few minutes to 30 hrs. Furthermore, different experiments have used different hearing effects as evidence of incipient damage. From the varied stimulus conditions in Table 1, it is clear that only scattered data on the broad problem exist, and that is is quite impossible to set rational Damage Risk Criteria which may apply to the generality of cases. Nevertheless, the problems are urgent, and NavUnderseaR&DCen in 1969[38,39] proposed on the basis of the experiments in Table 1 a design goal of 75 dB for airborne sound in living spaces of Class 688 submarines. This figure appears to be meant to serve both hearing conservation and habitability purposes, though the experiments from which it was drawn had most usually concluded (see Col. 3, Table 1) that for many pulse durations/duty cycles a Damage Risk Criterion of about 90 dB should suffice for hearing conservation (except for the British who used long (3.15-sec) pulses at high duty cycles).

j. NAVSUBMEDRSCHLAB Criterion of 90 dB Suggested in 1968 for Short Exposures.

In response to a request from NavUnderwaterSoundLab[40], NAVSUBMEDRSCHLAB[41] recommended for USS TIGRONE a Damage Risk Criterion of 90 dB if certain conditions were met concerning audiometric monitoring, personnel protection, and an operating "high-intensity noise-warning system."

3. Current Research.

a. Joint NUSC/NAVSUBMEDRSCHLAB Field Study on USS BERGALL (SSN-667) of 1970.

Measurement by NavUnderwaterSysCen of sound pressure levels due to active sonar on USS BERGALL (SSN-667)[42] revealed that acoustical hazardous areas certainly existed. The NUSC/NAVSUBMEDRSCHLAB Ad Hoc Group on Auditory Damage looked into the matter[43] and an audiometric field study on USS BERGALL (SSN-667) was conducted jointly by NavUnderwaterSysCen/NAVSUBMEDRSCHLAB[44] on a one-week cruise 6-12 July 1970 during which there was a 3.5-hr period of full-power echo-ranging, with pulses at about a 2% duty cycle. Only transient threshold shifts were found, and by comparing airborne levels in certain spaces with audiometric data, it was concluded that, for so short an exposure, a level of 95 dB was acceptable. In fact, over the last two years, USS BERGALL has utilized active sonar over 4,000 hours, with no known deleterious auditory effects, as the result of effective protection devices and continual monitoring audiometry[44b].

b. NAVSUBMEDRSCHLAB In-House Study of 1970.

An acoustic habitability/damage study was conducted in October 1970 by NAVSUBMEDRSCHLAB[45] using 85 dB 1-sec and pulses every 20

sec, 24 hrs/day for 5 days. Within a couple of days, the average hearing had declined by about 5 dB at the relevant frequencies but did not further decline for the next three days. It was reasoned that this asymptotic loss would not be exceeded by any possible permanent effect, and could therefore be disregarded as not constituting a criterion hearing loss. Nevertheless, it represented some physiological cost to the crewmen, and in fact required more than 24 hours for full recovery after the 5-day exposure; and it was concluded that 85 dB pulses of 1-sec duration at a 5% duty cycle are just on the verge of being noxious. Either a reduction in level, or in duty cycle, would be necessary for a conservative damage risk criterion.

c. NAVSUBMEDRSCHLAB Study on USS TIGRONE (AGSS-419).

On 30 March - 6 April 1971 NAVSUBMEDRSCHLAB conducted another audiometric survey during a week's cruise on USS TIGRONE[46]. In response to a request from NavUnderwaterSysCen,[47] NAVSUBMEDRSCHLAB interpreted the potential hazards of the noise as reported in[48], stating that hazard did exist, but that protective devices could render innocuous the levels in even the noisest workspaces; and that a damage criterion level of 85 dB should be set such that protective devices be worn at all times in compartments exceeding 85 dB. These recommendations were implemented by the CO, USS TIGRONE during the cruise, even extending to ear protection during sleep in certain compartments where the 85 dB criterion was exceeded. From the audiometric results it was concluded that no damage results from sonar levels even over 100 dB in workspaces for a one-week cruise if ear protection is insisted upon by the command and where a preliminary signal of high-level noise is instituted so that the men may don protective devices.

d. NavUnderseaR&DCen In-House Study of June-July 1970 (See Section F(1) Below).

e. NAVSUBMEDRSCHLAB In-House Study of 1971.

During August 6 through September 4, 1971 NAVSUBMEDRSCHLAB performed audiometry on 9 men subjected to 24 continuous days of 1-sec pulses at 85 dB every 60-seconds (duty cycle 1.6%). No average change in hearing was found at any frequency, and it can be concluded that dropping the duty cycle from 5%to 1.6% (actually increasing the recovery time after each pulse from 19 to 59 sec, a change in total acoustic energy of about 5 dB) has eventuated in a stimulus pattern innocuous for an indefinite time at 85 dB.

Conclusions on Hearing Conservation for Own-Ship Sonar.

Hazardous auditory conditions are certainly created by own-submarine active sonar in workspaces and living areas. Differences in sonar frequency, in pulse duration and duty cycle, and in recovery time between pulses, and in number of hours of active sonar per 24-hour day, for certain submarines and certain missions, render it necessary to provide an estimated Damage Risk Criterion for each set of conditions.

The USS TIGRONE, for example, as an experimental ship, uses a sonar frequency and mild echo-ranging schedules which will not be general throughout the S/M fleet, and which fortunately can be handled through the current provisions of the BUMED Hearing Conservation Program with protection, audiometry, education, etc. On the other hand, other ships using more damaging frequencies, for certain missions may go active 24 hours/day for long periods, and may very shortly be appreciably more intense than at this writing. It is not known on a truly scientific basis what criterion should be set for all frequencies, pulse durations, duty cycles and long-term exposure durations. The Damage Risk Criterion should be set such that 85% of Naval personnel are protected against a criterion loss consisting of permanent threshold shifts of more than 10 dB at 1 kHz, 15 dB at 2 kHz, and/or 20 dB at or above 3 kHz. It is obviously impractical and unnecessary to protect every man against any loss, however slight. Other techniques are available to deal with the unusual case of noise susceptibility. It is known that men on 4-8 hr watches in especially high noise level workspaces can, by protective devices and procedures, be maintained with no auditory problems. But for spaces inhabited by men off watch, as in eating, sleeping, etc., where the personal problems of noise are relatively more distressing, and the standard protective devices are at best annoying and uncomfortable, the appropriate Damage Risk Criterion is uncertain. For one set of conditions, namely, 1-sec pulses at 3.5 kHz at duty cycles about 2-5%, NAVSUBMEDRSCHLAB has shown that a criterion of 85 dB is just acceptable for current operations around the clock over a period of weeks. For a much heavier acoustic load the criterion would drop to 80 dB. If, for example, the frequency were to drop to 2 kHz so that auditory insult would occur at the frequencies important for speech, or pulse duration were to increase to 5-sec and duty cycle to 20%, even 80 dB might be questionable.

Fortunately, NAVSUBMEDRSCHLAB now has completed a 24-day study on one representative set of conditions (pulses at 1.7% duty cycle) and we can now use mathematical modeling to predict the correct Damage Risk Criterion as each parameter may be changed by the demands of the operating forces. Appropriate short-term experiments can now be performed in a psycho-acoustic laboratory to identify when necessary the physiological cost involved in lengthening pulses, increasing duty cycles, reducing interpulse intervals, or lowering frequency. It is NAVSUBMEDRSCHLAB's interpretation that it is the responsibility of BUMED to be ready with this information when needed by the operating forces and the material commands, and such research will continue at NAVSUBMEDRSCHLAB.

F: ACOUSTIC HABITABILITY DUE TO OWN-SHIP ACTIVE SONAR

In the preceding section it was noted that some surveys/experiments had treated both auditory damage and habitability aspects of own-ship active sonar. Of course, at some point the two are related, since obviously if a noise level is loud enough to cause permanent hearing damage, the space is uninhabitable by BUMED standards. A level might conceivably be innocuous to hearing and still by reason of its spectrum, time pattern, type of onset, etc., it might be at the least annoying or even lead to decrement in work performance.

A survey of the recent voluminous literature on noise pollution[49, 50 & 51] uncovers only a few papers directly of relevance here. We are interested only in repetitious and generally non-meaningful pure-tone pulses less than 85 dB as a limit set by the needs of hearing conservation. For such pulses, no deleterious consequences either physiological, neurophysiological (sleep) or psychological have ever been demonstrated. As reported in[50] the effects on a sleeping young man of repetitious pure-tone pulses in the 70-80 dB range are clearcut, as being no more than happens 300 times each night in association with transient K-complexes in the EEG. Jansen[49, p. 72] states that Damage Risk Criteria for sounds are also valid for responses of the autonomic system (circulation, respiration, etc.). Thus we need not seek to set Damage Risk Criteria for certain non-auditory effects at any lower level than for auditory effects.

a. Bolt, Beranek, and Newman Study of 1959 on BQS-6 Sonar for NavUnderwaterSysCen.

In the absence of basic research applicable to the acoustic habitability problem of this section, one can only turn to field studies, or laboratory simulations, of worst-case conditions. Bolt, Beranek, and Newman, Inc.[32] first suggested a habitability criterion of 80 dB for living areas and 75 dB in sleeping areas in a PERMIT class submarine using active sonar (BQS-6) assuming 1-second pulses every 25-seconds for 3-5 days/mo.

b. NAVSUBMEDRSCHLAB In-House Study of 1961.

NAVSUBMEDRSCHLAB[24] found that even 90 dB was habitable for a time with 1/4-sec pulses at 3.5 kHz at 5% duty cycle. After 30 hrs of these pulses, 12 Navy enlisted men incarcerated in the NAVSUBMEDRSCHLAB Sound Suit spaces, built for just such a purpose, were well acclimated to the pulse and felt they could eat, sleep, etc., indefinitely at such a level.

c. Bolt, Beranek, and Newman Recommendations for USS TIGRONE in 1961.

Bolt, Beranek, and Newman, Inc. recommended[33] for USS TIGRONE (AGSS-419) (actively echo-ranging at 4% duty cycle) that a habitability criterion of 75 dB be set for sleeping/eating/relaxation areas.

d. British Field Study of 1964.

The British[34] for their lower frequency, longer pulse duration and heavy duty cycle (10%),stated that 75 dB was habitable in living spaces, but suggested 70 dB in sleeping quarters.

e. NAVSUBMEDRSCHLAB Proposal of 1967.

As a result of a visit on 26 January 1967 to NAVSUBMEDRSCHLAB by Mr. J. P. Jenkins of NAVSHIPSYSCOM, a letter was received by NAVSUBMEDRSCHLAB[52] requesting the submission of a program plan to establish auditory Damage Risk Criteria for, among other equipments, an AN/BQS-13 sonar (Active), together with cost estimate. Inasmuch as NAVSUBMEDRSCHLAB was already aggressively pursuing such a program in informal cooperation with the NavUnderwaterSysCen, Bolt, Beranek, and Newman, Inc., and submarines in this geographic area (e.g., BERGALL, TIGRONE), the expression of interest and possible support from another Navy Bureau was especially welcomed. An extensive proposal was submitted[53] specifying work on habitability of prolonged stimulation (paragraph 7(2)), specifically, "the types of functions (sleep, recreation, work, etc.) which may be performed under various intensity levels."

No response to this proposal was received, indicating, it was felt, a reluctance by NAVSHIPSYSCOM to enter so obviously a medical/paramedical field for which BUMED was patently the more appropriate monitor.

A review of [53] was attempted in an NavUnderwaterRandDCen informal memo from Code D605 to Code D551, and transmitted to NAVSUBMEDRSCHLAB, Code 433 [39 w/encls], but the comments simply reiterated the 90 dB criterion for the Conformal Planar Array System (on USS SPOKANE) [39, enc. 1, para. 5] and do not bear on current problems.

f. NavUnderseaR&DCen Recommendations of 1969.

For Class 688 submarines, NavUnderseaR&DCen, on the basis of experiments from other laboratories as listed above, suggested a habitability criterion of 75 dB for living spaces[38, 39], a suggestion concurred in by the Preventive Medicine Code of BUMED[39b], which stipulated, however, that the NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics look into the matter.

g. British Recommendations of 1970.

The British[55] have recently formulated a habitability criterion of 70 dB for long pulses and high duty cycles.

h. NavUnderseaR&DCen Sleep Study of 1970.

In a joint study between NavUnderseaR&DCen and NavPsychiatricResUnit[56] the heart rate and EEG of one man was recorded while exposed to 1/3-sec pulses of 3.5 kHz at 1.25% duty cycle at 65 dB every night for 3 consecutive nights. Nothing alarming was seen. In the summer of 1970 these pulses were given at 75-80 dB to NURDC at their desks for 6.5 hours daily for 6 days. It was found that 75 dB was acceptable, though with "some

grumbling", but that 80 dB was not acceptable[57].

i. NavUnderwaterSysCen/NAVSUBMEDRSCHLAB Study Group Established 1970.

In June 1970, NavUnderwaterSysCen set up an Ad Hoc Study Group on "Hearing Damage and Acoustic Isolation" with three members from NAVSUBMEDRSCHLAB. It was stated that "one of the objectives of the program will be to develop specifications for acoustic habitability in submarines"[43]. This Study Group arranged for habitability data on USS BERGALL (SSN-667) and on 6-12 July 1970 Mr. Chattin, a Human Factors observer from NAVSUBMEDRSCHLAB, collected habitability survey data on BERGALL[44], with encouraging results; for a few hours of high-level noise no complaints or effects of any kind were noted.

j. NAVSUBMEDRSCHLAB In-House Study of 1970.

This Study Group received a draft of a proposed NAVSUBMEDRSCHLAB in-house 5-day habitability study directed toward the sonar pulse problem in Class 688 submarines, and rendered advice and guidance from the point of view of the operating forces. On 26 October - 2 November, 12 submarine enlisted men were incarcerated for 8 full days in the NAVSUBMEDRSCHLAB habitability suite and given 5 consecutive days of pulses (5% duty cycle) at 85 dB[45]. Very complete pre- and post-confinement medical, physiological, and psychological tests were administered as is the custom of NAVSUBMEDRSCHLAB in its long series of submarine habitability studies extending over three decades; and a battery of 24 tests of all types, including psychomotor performance, vigilance, etc. was administered, many of them every day for the 8 days. Aside from a slight temporary perturbation of the audiogram, and an asynchrony of the visually-evoked EEG response, for which control experiments have not yet been run, the effect of the sonar pulses was entirely negligible after a 36-hr adaptation. Any effects in the tests are easily explained on the basis of learning, monotony, lack of sleep from some late card games, an end-spurt which began 12 hrs before termination of the pulses, and other features of the confinement having nothing to do with the pulses as such.

k. NAVSUBMEDRSCHLAB Field Study on USS TIGRONE of 1971.

During an NAVSUBMEDRSCHLAB audiometric study of 30 March thru 6 April 1971 underway on USS TIGRONE (AGSS-419)[46], some attempt was made to collect habitability data. No problems came to the attention of the NAVSUBMEDRSCHLAB representative or to the Hospitalman aboard, other than auditory problems, which could be attributed to sonar pulses levels of 85 dB or less in living/sleeping compartments. The report states "No man reported to Sick Bay with other than the usual complaints, or one for which a psychosomatic basis could be suspected. There was no unusual use of aspirin or other mild tranquilizers, and no case of insomnia came to light. On the contrary, the whole cruise was

characterized by the highest morale. Officer-enlisted rapport was excellent, the atmosphere pleasantly informal. During the 10 days aboard, this writer never heard an argument and rarely a word of exasperation."

On this cruise at least, a habitability criterion of 85 dB was validated.

l. NavUnderseaRandDCen In-House Study of 1971.

In June 1971 a habitability study was performed at NavUnderseaR&DCen involving 5 days of pulses at 80 dB followed immediately by 10 days at 85 dB, as one of a series of studies on acoustic habitability proposed by NAVSHIPSYSCOM[58] with inputs not only from NavUnderseaR&DCen but also the NavUnderwaterSysCen, NAVSUBMEDRSCHLAB, Subase-New London, NAVPERSTRARESLAB, NAVMEDNEUROPSYRSCHUNIT and Flt ASW School, San Diego, with funding to all these activities as needed. Informal communication prior to a full analysis of these data reveals[59] that at the chosen stimulus conditions (3/4-sec pulses every 37.5 sec) a level of 80 dB was habitable and had no effect on military-type work performances for at least 5 days, whereupon the level was raised to 85 dB for 10 days immediately following the 80 dB exposure. Although there was a temporary threshold shift asymptotic at 17 dB on the average for 2 subjects out of 20 at 4 kHz, and an uncertain shift in a third subject, these losses even if they should prove permanent, are well within the threshold shift of 20 dB at 3 kHz and above which[4] has been stated is a significant loss. As to habitability as such, there seemed to be no effect of the 85 dB pulses on other functions than hearing. Obviously, a full report on this experiment will be welcomed as of considerable importance and as being pitched right on or near the finally correct habitability criterion.

m. NAVSUBMEDRSCHLAB In-House Study of 1971.

The 30-day NAVSUBMEDRSCHLAB habitability study of 6 August - 4 September 1971, at 85 dB was shown in the previous Section E to have had no significant effect on hearing, and no indication is seen that the sonar pulses had any effect whatsoever on the men's health, well-being, or psychological state. Should this prove not to be the case, addressees will be informed immediately.

An especially full battery of medical, psychological, physiological and behavioral tests was administered, many of them daily. Every effort was made to simulate life in a submarine, with military duties and inspections by the Chief of the Boat and by NAVSUBMEDRSCHLAB medical officers, and with certain of the tests directly simulating submarine tasks such as sonar watches, etc., as planned and administered by the Military Applications Branch of NAVSUBMEDRSCHLAB with the advice of CDR BURKE, SUBDEVGRU TWO. CRD BURKE's participation in planning is gratefully acknowledged.

All nine subjects exposed to the pulses completed the confinement in good physical condition and in good

frame of mind. For example, the five rated Sonar Technicians in the group completed a detailed experiment during each man's daily 2-hr sonar watch, on the 50% recognition differential either alerted or unalerted using a realistic sonar stack and wheel. On many of the other tests the whole group yielded normative data on learning, vigilance, tracking behavior, etc., which was of such quality to be useful to the various Branches for other purposes as well. A tentative conclusion now is that after perhaps a day or two adaptation for some men, pulses of 85 dB no oftener than once/min are well within the habitability limits for exposures of the order of several weeks.

n. NAVSHIPS Habitability Criterion of 1970 for Broad-Band Noise.

(The NAVSHIPS habitability criterion of 70 dB for submarine living spaces[60] should be mentioned here for completeness, but this criterion was based solely upon noise surveys of such spaces involving steady-state broadband noises, never active sonar pulses. The acceptable level of 70 dB was chosen as being 2 standard deviations above the average noise level of a sample of submarines, and thus is based upon the state of the shipbuilding art and not upon research concerning human responses to sound. Its provisions are inapplicable here).

Conclusions on Habitability.

What little guidance exists in the literature hints at the conclusion that the human's adaptive reactions to sounds are such that effects of sounds on the circulatory, digestive, neurological, and endocrine systems do not cumulate and threaten permanent damage unless the levels are high enough (i.e., around 80 - 90 dB) to begin to cumulate in the auditory system also. A variety of bodily responses to such levels of sounds as in the case of sonar pulses can of course be recorded from the waking or sleeping human at levels below those causing auditory damage - indeed, even faint near-threshold levels can affect the EEG; but there is no shred of evidence that these responses to faint sounds are deleterious or have any effect other than to facilitate the organism's sampling his environment. The statement that a sonar pulse level exacts a significant physiological cost even though it is demonstrably not deleterious to hearing, is not validated today by any experiment showing the responses to such sounds as having cumulative and undesirable effects on extra-auditory systems of the body.

Therefore, the Navy's present question on the habitability of sonar pulses can probably not be answered by laboratory studies on circulation, digestion, sleep, etc., but rather by field studies on ships underway and/or by more or less crude simulations of such cruises. At the moment NAVSUBMEDRSCHLAB takes the position that a habitability criterion can be set for rather specific sets of sonar pulse conditions. Levels of 85 dB in living/sleeping quarters of both USS TIGRONE (AGSS-419) and USS BERGALL (SSN-667) while actively echo-ranging at sea, have been shown to be acceptable to well-motivated Navy personnel and to lead to no demonstrable deterioration of performance. During simulated

cruises using pulses at 1.7 - 5% duty cycles, a level of 85 dB has been shown to be habitable for 5 days, (NAVSUBMEDRSCHLAB), 10 days (NavUnderseaR&DCen) and (24 days (NAVSUBMEDRSCHLAB). For conditions no more acoustically onerous than these, a habitability criterion of 85 dB is correct for continuous (24 hrs/day) exposures for a month or more. For significantly longer pulses and larger duty cycles, if in the future these should be dictated by operating requirements, the criterion should perhaps be no greater than 80 dB.

It is recommended herewith that should the Navy Submarine Fleet propose a substantial (5+ dB) increase either in pulse duration (i.e., from 1 to 3+ sec) or duty cycle (i.e., from 2 to 7+%) the habitability criterion drop tentatively and conservatively to 80 dB and that a brief psycho-acoustic laboratory study with mathematical modeling be performed on the effect of the added pulse duration and/or duty cycle, in order to calculate from the NAVSUBMEDRSCHLAB 24-day habitability study exactly what levels of the new pulse conditions would not produce further deterioration of performance.

Unless the predictions of such an experiment were proved incorrect by subsequent auditory/habitability surveys at sea, as NAVSUBMEDRSCHLAB proposed to continue to do and/or by the on-going NAVSUBMEDRSCHLAB Longitudinal Health Study, it is recommended that no further habitability studies involving long confinements be performed by the Navy.

SUMMARY AND RECOMMENDATIONS

In order to support current recommendations and criteria in the general field of hearing conservation and acoustic habitability in submarines, and to serve as a guide for further research where needed, this report reviews the status of six conditions in submarines which may affect the hearing/health/performance of the crew.

a. Broad-Band Continuous Noise.

The provisions of the Navy's Hearing Conservation Program (BUMEDINST 6260.6B) are quite adequate to handle such noises, and no further research is needed for the submarine force.

b. Impulsive Sounds (Gunfire).

Real auditory hazards exist in the Navy, but not primarily in submarines. Research on the effects of specific acoustic aspects of gunfire should be pursued, and on the effects of total number of rounds, recovery time between rounds, etc.

c. Effects of Active Sonar on Swimmers and Divers.

Real auditory hazards exist, and it is recommended that BUMED accelerate its basic research on underwater hearing and its efforts to prepare rational Damage Risk Criteria.

d. Effect of Surface Ship Sonar on Submarine Sonar Technicians.

Real auditory hazards exist, but a fail-safe voltage limiter can reduce the

problem substantially. Extensive research must be performed on (1) the trade-off between the limiting level vs the loss of acoustic information through the resulting distortion, and (2) the best of several electronic methods of processing the input to the sonar headset.

e. Own-Ship Active Sonar and Auditory Damage.

Own-submarine sound pressure levels during active sonar in certain workspaces are quite unacceptable by any criterion. No workspace, however, is so noisy that standard ear plugs/muffs cannot adequately protect all men; where such devices cannot readily be worn for more than a few hours (as in eating/relaxation/sleeping areas) a Damage Risk Criterion of 85 dB will protect 85% of the men in current operations from experiencing a significant hearing loss. If worse conditions should prevail, e.g., pulse durations as long as 3-sec, or duty cycle exceeding 10% on-time, the criterion should be 80 dB. Audiometric monitoring surveys at sea during the first such exposure(s) should be performed. Research in the near future should consist of fairly brief in-house laboratory studies on the specific effects of pulse duration, duty cycle, recovery time between pulses, etc., in order to predict the auditory effects of new operating conditions when they are first proposed.

f. Own-Ship Active Sonar and Acoustic Habitability.

A rational acoustic habitability criterion is determined to be approximately the same as a hearing conservation criterion for sonar pulses. No instances have developed of deterioration in the health/psychological status/performance of men exposed to SPLs which do not also affect the audiogram. This has proved true for 3 days in a NAVSUBMEDRSCHLAB In-House Habitability Study in 1961, for 5 days in a NAVSUBMEDRSCHLAB In-House Habitability Study in 1970, for 5 days in a NAVSUBMEDRSCHLAB Field Study on USS TIGRONE in 1971, for 10 days in a NavUnderseaRandDCen In-House Habitability Study in 1971, and for 24 days in an NAVSUBMEDRSCH-LAB In-House Study in 1971.

Accordingly, a habitability criterion of 85 dB for sonar pulses 24 hrs/day will serve for well-motivated healthy young men for at least several weeks. No further in-house acoustic habitability studies need be performed at this time; field surveys will suffice on ships which may at some future time increase substantially the acoustic load on eating/relaxation/sleeping areas. The 20-year ongoing NAVSUBMED-RSCHLAB Longitudinal Health Study is an additional monitoring technique to insure the long-range applicability of these recommendations for submariners.

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13. ABSTRACT

Several acoustic conditions in submarines are considered which are potentially hazardous to hearing and/ or ship's habitability. Recommendations are made and priorities suggested for further research:

(1) Broad-band noise is now well covered by the BUMED Hearing Conservation Program.

(2) The effects on the ear of impulsive noise (rockets, gunfire) are not well known, but these are not primarily submarine problems.

(3) The fundamental characteristics of underwater hearing are largely unknown and submarine medicine should sharply increase its basic and applied research here.

(4) Intense sounds in the sonar headphone occasionally exist, but some applied research here should solve this relatively simple problem.

(5) Own-ship echo-ranging creates hazardous levels, but at duty stations men can wear ear protective devices. In living areas where these cannot be used around the clock, a Damage Risk Criterion of 85dB has proved acceptable for 24 hours with sonar as now used. If future operations should materially increase the acoustic load on the ear, some short-term laboratory studies and monitoring at sea should be the techniques of choice.

(6) Acoustic habitability with own-ship echo-ranging has proved in repeated studies not to be a problem unless sound levels are intense enough also to affect the ear adversely. Thus the ear, as the body's most sensitive system to sound, is also the most fragile, and can serve as the best index of habitability. There is no Navy need for further confinement studies on the effect of sonar pulses on non-auditory systems of the body.

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